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Reasons for Failure of Waterproofing System in Subway Stations with Complex Strata

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Abstract: With the rapid development of urban subway transportation networks, the waterproofing system of subway stations in complex strata plays a crucial role in ensuring the normal operation of underground stations. This paper analyzes the reasons for the failure of waterproofing systems in subway stations, focusing on issues such as self-waterproofing of concrete structures, waterproofing of detailed structures in subway stations, and failure of flexible waterproofing materials. Through case analysis and impact analysis, combined with construction characteristics, the paper summarizes the reasons for the failure of waterproofing systems in subway stations with complex strata and proposes preventive measures and repair methods.

Keywords: Subway station; Waterproofing system; Cause of failure; Treatment measures Chinese Classification Number: Document Identification Code: A Article Number.

1. Introduction

With the acceleration of urbanization and population concentration, subway transportation has gradually become an indispensable mode of transportation in modern cities. As an important part of passenger boarding and site transfer, the waterproofing system of subway stations is also crucial. The function of the waterproofing system is to ensure the dryness and safety of underground stations and tunnels. The failure of the waterproofing system will have a serious impact on the normal operation of subway stations, including water leakage, geological disasters, and equipment damage. Especially in subway stations with complex strata, the underground environment is complex and variable, facing various geological and hydrogeological challenges, including high groundwater levels, complex stratum structures, and groundwater seepage. These underground environments pose significant challenges to the construction and maintenance of waterproofing systems in subway stations. In engineering practice, waterproofing system failures such as seepage often occur in subway stations. Therefore, identifying the reasons for the failure of waterproofing systems in subway stations with complex strata and implementing preventive measures have important theoretical research and engineering application value.

Zhu Mingjiao[1] analyzed the failure of self-waterproofing in subway station concrete structures. Based on a series of calculations on concrete crack width, it was found that constraint stress affects concrete cracks. It was proposed that the degree of constraint should be reduced in construction plans, and measures should be taken in both construction and materials to minimize temperature differences (shrinkage differences), improve ultimate tensile strength, reduce the degree of constraint, and achieve comprehensive control of cracks. Dai Mingda [2], relying on the Tianjin Binhai New Area subway, analyzed the leakage issues at construction joints and post-pouring belts. A new type of waterstop was adopted, and the waterproofing system at key parts such as construction joints and post-pouring belts in subway stations was optimized. New prefabricated waterproof products were used, and it was proven through practice that these measures effectively solved the waterproofing challenges at key parts of subway stations. Lei Yongsheng [3] and others conducted a statistical analysis of waterproofing membranes used in multiple subway lines across various regions by deeply analyzing the locations and causes of leaks. They proposed issues to be aware of and improvement methods for the selection and construction of waterproofing membranes in subway stations, and developed a new type of waterproofing system. Su Bowen[4] analyzed the causes of waterproofing system failures in subway stations due to construction personnel, construction management, and construction operations, and provided suggestions on related issues to reduce the impact on project quality.

Based on this, this paper summarizes the causes of failures in the self-waterproofing of concrete structures, detailed structural waterproofing, and flexible waterproofing in the waterproofing systems of subway stations in complex strata. It proposes targeted suggestions and measures based on these causes, providing references and insights for the construction and maintenance of subway station waterproofing systems in the future.

2. Causes of Waterproofing System Failures in Subway Stations in Complex Strata

The waterproofing system of a subway station is one of the many systems in a subway. In recent years, frequent subway leakage incidents have been largely caused by the failure of the waterproofing system. The waterproofing system is primarily designed to effectively isolate the station structure from external groundwater and soil, preventing groundwater and stagnant water from penetrating the subway station structure. According to regulatory requirements, subway waterproofing design follows several major principles: "prevention first, combination of rigidity and flexibility, multiple lines of defense, and comprehensive management." Based on these principles, large-area concrete structures form the first line of defense through self-waterproofing. Detailed structural waterproofing at key points such as construction joints, deformation joints, and post-pouring belts forms the

second line of defense. Flexible waterproofing materials form the third line of defense. These three lines of defense complement each other to form the subway station waterproofing system, as shown in Figure 1. When the waterproofing system fails, it is mainly due to the following reasons.

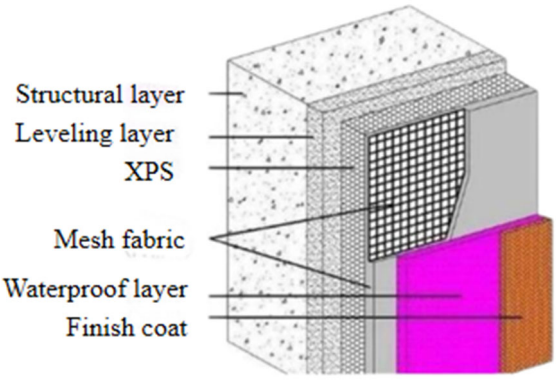

Figure 1. Schematic Diagram of the Waterproofing System

2.1. Failure of Self-Waterproofing in Concrete Structures

The principle of self-waterproofing in concrete structures refers to preventing water penetration through the density and hydrophobicity of the concrete itself. In the waterproofing system, the self-waterproofing of concrete structures is the most important line of defense among the three, especially in the complex hydrological environment of subway stations in complex strata, which places higher demands on the waterproofing of the main structure [5]. Concrete cracking is the main cause of waterproofing failure. During the construction of subway stations, concrete is used extensively, and the station's roof, floor, and side walls are all constructed with concrete. After the concrete is poured, inadequate curing can easily lead to surface cracks and later shrinkage [6]. In the construction of subway stations in complex strata, there are high requirements for the strength, stiffness, and durability of the concrete. However, in engineering design, the mix proportion of concrete often lacks rationality and scientificity, and external load stress can easily cause structural cracking and deformation-induced cracks [7].

2.2. Failure of Detailed Structural Waterproofing

Statistical data on leaks in subway stations show that construction joints and deformation joints are the main locations where leaks occur. Therefore, special attention should be paid to the waterproofing of these joints [8]. Deformation joints in subway stations are generally set at the connections between stations and entrances/exits, areas that are often subject to concentrated deformation. Construction joints are also weak points in terms of load-bearing and waterproofing, making them more susceptible to environmental influences compared to other structures [9]. Currently, the waterproofing treatment of construction joints mainly involves the use of rubber waterstops and cement-based permeable crystalline materials to treat the surface structure of the working face. However, due to the structural characteristics of construction joints, there can be poor adhesion between concrete sections [10]. Additionally, rubber waterstops may not be tightly connected to the concrete, leading to leaks in subway stations.

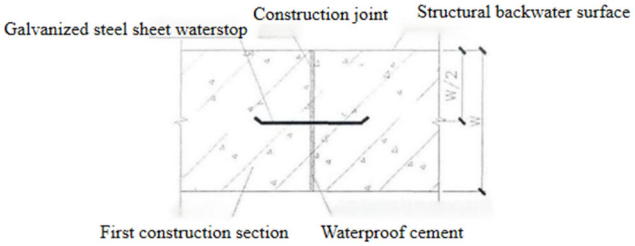

Figure 2. Waterproofing Structure Diagram of Construction Joint

2.3. Failure of Flexible Waterproofing Materials

The flexible waterproofing of subway stations is a type of waterproofing membrane relative to the self-waterproofing of rigid concrete structures. Flexible waterproofing in subway stations is generally treated with flexible waterproofing belts, flexible sealants, or flexible waterproofing membranes. These materials have good elasticity, durability, and impermeability, maintaining excellent waterproofing effects even when structural deformation or cracks occur [11]. However, during the concrete pouring process, the sand-covered surface of the sidewall waterproofing membrane is easily contaminated by concrete and is difficult to clean, significantly weakening its self-adhesive properties and affecting the sealing of the waterproofing membrane. In current construction, PVC waterproofing boards are often used, but due to their susceptibility to deformation, bending, and poor durability, the third line of waterproofing defense can fail [12-13].

2.4. Impact of Construction Operations

The impact of subway station construction operations on the waterproofing system is crucial. Improper construction practices can lead to the failure of the waterproofing system and even endanger the safety of the subway station. In actual engineering construction, the high mobility of construction workers and the lack of professional waterproofing training can lead to issues in the quality of the waterproofing project, resulting in the failure of the waterproofing system during later stages of station construction. Project managers often do not place enough emphasis on the quality of the waterproofing project, lack the necessary skills, and are not sufficiently aware, failing to promptly identify and rectify existing waterproofing quality issues.

3. Case Analysis and Preventive Measures

The establishment of a subway station's waterproofing system requires comprehensive consideration of material selection, construction management, maintenance, and other aspects [14] to ensure that the waterproofing system can effectively and durably perform its waterproofing function, maintaining the safety and stability of the station's building structure.

3.1. Enhancing the Self-Waterproofing of Concrete Structures

In practical engineering, the self-waterproofing of subway station concrete structures can be improved by reducing the

development of concrete cracks. According to subway design specifications, the concrete mix design must meet strength and impermeability grade requirements. To reduce shrinkage-induced cracks, measures such as adding expansion agents to the concrete can be taken to minimize concrete shrinkage, thereby enhancing the crack resistance of the concrete and preventing the occurrence of cracks.

In practical applications, Liu Guobin [15] et al. used low-heat slag cement in the design of concrete for subway stations to reduce the heat of hydration and the resulting shrinkage cracks. Qi Feng [16] added polypropylene fibers to the concrete of Shanghai Metro Line 7 to increase the density of the concrete, thereby improving the structural self-waterproofing of the concrete. Tests showed that the addition of fibers significantly improved the flexural and tensile strength of the concrete, preventing or reducing the formation of cracks and enhancing the overall crack resistance of the concrete.

3.2. Strengthening the Design and Treatment of Detailed Structural Waterproofing

To avoid the failure of the waterproofing system due to construction joints and deformation joints, it is necessary to pay attention to the selected location during the design of construction joints, avoiding areas with abundant groundwater. When fixing the waterstop, ensure that it is firm and reliable, without any twisting or deformation [17]. Before pouring the concrete, the concrete surface should be roughened or washed with a high-pressure water gun. The concrete at the waterstop should be fully vibrated to ensure the density of the concrete at the construction joint. In Beijing Metro Line 16, a cement-based permeable crystalline waterproof coating was first applied at the construction joint, followed by the installation of a single-piece water-swellable waterstop, and the use of full-section grouting pipes to achieve a better waterproofing effect [18].

3.3. Rational Selection of Flexible Waterproofing Materials

In flexible waterproofing, the selection of materials and construction operations are key to the quality of waterproofing. When selecting waterproofing membranes, we should fully consider the geological conditions, the structural design of the station, and the form of the retaining structure, and choose flexible waterproofing materials that have good puncture resistance, adhere closely to the base surface of the main structure, do not blister, do not allow water migration, are environmentally friendly, have good flame retardant properties, ensure the safety of construction personnel, and are non-toxic and odorless [19]. Currently, polymer self-adhesive waterproofing membranes commonly used in construction are prone to opening and falling off, and PVC waterproofing boards have issues such as poor durability and susceptibility to bending and deformation. In Xiamen Metro Line 3, a new EVA self-adhesive waterproofing board was used. Through comparison, it was found that the new EVA self-adhesive waterproofing board has strong water migration resistance, high tensile strength, strong resistance to ground deformation and local impact damage, and high cost performance.

3.4. Strengthening Construction Management

Strengthening the quality and management of construction operations in subway stations is an important measure to ensure the effectiveness of the waterproofing system. It is essential to ensure that construction personnel fully understand and strictly adhere to relevant specifications and technical standards, including the selection of waterproofing materials, construction techniques, and requirements for construction temperature and humidity. Systematic training and technical guidance should be provided to construction personnel to improve their waterproofing construction skills and operational standards, ensuring professional and standardized construction operations. A robust quality management system should be established to comprehensively supervise and inspect the construction site, promptly identify and resolve issues during the construction process, and ensure that the construction quality meets standard requirements.

4. Conclusion

This paper summarizes the main causes of waterproofing system failures in subway stations in complex strata and the corresponding preventive measures. It analyzes the specific reasons for the failure of self-waterproofing in concrete structures, the failure of detailed structural waterproofing, and the failure of flexible waterproofing materials, as well as the impact of construction operations on waterproofing projects.

In summary, we should establish a scientific and effective waterproofing system during the construction of subway stations, enhance the compactness of concrete, and reduce the development of concrete cracks. Since water leakage mainly occurs at deformation joints and construction joints in stations, reasonable design should be carried out based on environmental conditions and structural forms during structural design, with multiple layers of protection to ensure reliable waterproofing. When selecting flexible waterproofing membranes, choose those that meet the design requirements for waterproofing, environmental protection, excellent performance, ease of construction, and cost-effectiveness. Establish a professional construction team to ensure the quality of waterproofing construction.

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